

THEORETICAL DESCRIPTION OF KHZ QPOS IN ACCRETING LMXB SYSTEMS

BANIBRATA MUKHOPADHYAY *

*Astronomy Division, P.O.Box 3000, University of Oulu, FIN-90014, Finland;
bm@cc.oulu.fi*

SUBHARTHI RAY †

*Instituto de Física, Universidade Federal Fluminense, Niterói 24210-340 RJ, Brazil;
sray@if.uff.br*

JISHNU DEY ‡

*UGC Research professor, Department of Physics, Maulana Azad College, 8 Rafi Ahmed
Kidwai Road, Kolkata-700013; deyj@giacsl01.vsnl.net.in*

MIRA DEY §

*Department of Physics, Presidency College, 86/1 College Street, Kolkata-700073;
deyj@giacsl01.vsnl.net.in*

We describe kHz QPOs from the hydrodynamical model of accretion disks for LMXB systems. Out of the pair, the higher frequency originates due to the viscous effects of an accretion disk involving the formation of shock, while the lower one is due to the Keplerian motion of accreting matter. Comparing our results with observations for two fast rotating compact stellar candidates, namely, 4U 1636–53 and KS 1731–260, we find that they match to a very good approximation.

One of the most important *questions* in present day astrophysics is the origin of quasi-periodic oscillations (QPO) observed from compact objects. Also the particular interests are behind those which are of kilohertz (kHz) order and are supposed to originate from neutron star candidates in the low mass X-ray binary (LMXB) system. Interesting point is that those kHz QPO frequencies are observed in a pair for a particular source and difference of those pair frequency is almost same or half of the spin frequency of the compact star. Moreover sometimes there is the existence of side-band(s) of those QPOs. Since their discovery, several (theoretical)

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†Present address: IUCAA, Post Bag 4, Ganeshkhind, Pune-411007, India; sray@iucaa.ernet.in

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models have been proposed to describe their origin (e.g. see references^{1,2}) but to our knowledge none of them could *completely* explain all of the related phenomena.

Here we propose one such model to describe a few aspects of QPO from the hydrodynamical description of accretion disks. As the QPOs originate from close to the compact object, an inner edge of the accretion disk exists in that region but in the sub-Keplerian regime, because the gravitational attraction of compact objects essentially wins over any other forces at that extreme inner region.

Recently, a number of pseudo-Newtonian potentials have been proposed which describe the time varying as well as steady-state relativistic properties of accretion disks around rotating compact objects with hard surface (e.g., neutron star but not black hole)^{3,4}. Therefore, here we like to describe our disk in pseudo-Newtonian manner incorporating the relativistic properties approximately. A detailed discussions about the model equation set we need to solve for accretion disk structure, are given in Mukhopadhyay & Ghosh⁴, and are beyond of present scope.

The formation of shock in accretion disks around the compact object was discussed by several independent groups (e.g. see references^{5,6,7}). These shocks can be formed in an accretion disk if a certain set of conditions are satisfied simultaneously, which may happen for a specific parameter regimes of the sub-Keplerian disk^{5,8}.

Solving the set of disk equations⁴ and following earlier works^{5,9}, here we argue that when the shock is formed in an accretion disk, the cooling (t_{cool}) and advection (t_{adv}) time scale of matter from the shock location to the surface of a compact object are responsible for the oscillatory behaviour of shock that is related to the QPO. If $t_{\text{cool}} \sim t_{\text{adv}}$, the corresponding upper kHz QPO frequency can be found as

$$\frac{1}{\nu_h} = t_{\text{adv}} = \int_{x_s}^{x_{\text{in}}} \frac{dx}{v}, \quad (1)$$

where x_s and x_{in} are the location of shock and the radius of the star respectively.

On the other hand, the lower QPO frequency may arise due to the Keplerian motion of the accreting fluid¹. According to the pseudo-Newtonian potential³, the Keplerian angular frequency of the accretion flow is given as

$$2\pi\nu_K = \Omega_K = \frac{1}{x^{3/2}} \left[1 - \left(\frac{x_{\text{ms}}}{x} \right) + \left(\frac{x_{\text{ms}}}{x} \right)^2 \right]^{1/2}, \quad (2)$$

where x_{ms} is the radius of marginally stable orbit related to the specific angular momentum (J) of the compact object³. According to our model, this ν_K is the lower kHz QPO frequency that varies with the angular frequency of the compact object. If we know the angular frequency of the compact object and the Keplerian radius of the corresponding accretion disk, this can be calculated.

As an example, Fig. 1 shows the variation of accretion speed for various parameter regimes around 4U 1636–53 which has been identified as one of the fast rotating compact star showing a pair of kHz QPO. The outer shock locations (if there are two shocks) are usually responsible for higher QPO frequency. In Table 1

we enlist all our results which clearly show a very good agreement with observations. A detailed discussion of a similar table is given elsewhere⁹.

Table 1

source	α	r_s (km)	r_k (km)	J	M (M_\odot)	R (km)	ν_h Hz	ν_K Hz	observed	
									HF(Hz)	LF(Hz)
4U 1636–53	0.05	15.37	18	0.2877	1.18	7.114	1030.8	719.7		700
	0.02	14.27	19	0.2877	1.32	7.23	1019.2	705.2	1030	
	0	13	17	0.2877	0.991	6.828	1005.2	715.2		
KS 1731–260	0.05	15.37	15.2	0.2585	1.106	7.013	1155.4	907.6		898
	0.02	14.27	16	0.2585	1.23	7.16	1174	892.6	1159	
	0	13	14.5	0.2585	0.893	6.64	1151.9	863.1		

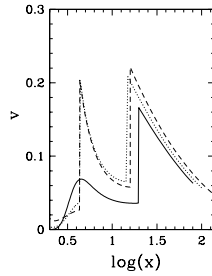


Fig. 1: Variation of accretion speed (in unit of light speed) as a function of radial coordinate (in unit of GM/c^2) around 4U 1636-53. Solid, dotted and dashed curves are respectively for inviscid flow, and two different viscous flows with viscosity, $\alpha = 0.02$ and $\alpha = 0.05$. Here, $J = 0.2877$.

It is perhaps for the first time such a theoretical calculation is presented which matches with the observation to such a satisfactory limit. Also the model can be checked with the observations for other candidates. A very interesting outcome is that the mass and radius of the compact star, supplied in our calculation to match with observations, are not in accordance with the conventional neutron star equation of state, but that of a strange star¹⁰. Therefore this may also justify the existence of strange stars.

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